The nitrogen and phosphorus budget of Flanders: a tool for efficient resource management

J. Coppens[*], **E. Meers**[**], **N. Boon**[***], **J. Buysse**[****], **S. E. Vlaeminck**[*****/******]

[*] Laboratory of Microbial Ecology and Technology (LabMET), Ghent University, Coupure Links 653, 9000 Ghent, Belgium, joeri.coppens@ugent.be

[**] Laboratory of Analytical and Applied Ecochemistry, Ghent University, Coupure Links 653, 9000 Ghent, Belgium, erik.meers@ugent.be

[***] Laboratory of Microbial Ecology and Technology (LabMET), Ghent University, Coupure Links 653, 9000 Ghent, Belgium, nico.boon@ugent.be

[****] Department of Agricultural Economics, Ghent University, Coupure Links 653, 9000 Ghent, Belgium, j.buysse@ugent.be

[*****] Laboratory of Microbial Ecology and Technology (LabMET), Ghent University, Coupure Links 653, 9000 Ghent, Belgium, siegfried.vlaeminck@ugent.be

[******] Department of Bioscience Engineering, University of Antwerp, Groenenborgerlaan 171, 2020 Antwerpen, Belgium

Abstract: The region of Flanders in Belgium has due to its high population density, intensive livestock production and industry a nutrient surplus available in waste streams. It therefore possesses a large potential towards the recovery and reuse of nitrogen and phosphorus. In this study, a substance flow analysis study for nitrogen and phosphorus is presented, in which the fluxes, stocks and hot spots of both nutrients are quantified throughout the economy. The predominant nutrient fluxes are found within the food supply chain, which connects industry, agriculture and consumption. This food supply nexus results in an overall fertilizer-to-food efficiency of 26% N and 22% P. At the end of the production and consumption chain, a total of 17 kg N cap^{-1} yr^{-1} and 8.3 kg P cap^{-1} yr^{-1} of nutrients ends up in waste streams. Only a fraction of these nutrients (17% of N and 12% of P) is currently recycled. Several nutrient recovery strategies, both for chemicals and single cell protein production, were therefore evaluated for their economic feasibility and their impact on the energy demand of the food supply chain.

Keywords: mass flow analysis, nutrient recovery, waste management

Introduction

Nutrients such as nitrogen and phosphorus are key elements for plants and animals and are therefore essential for securing the food supply chain. The global challenges that face us, such as population growth and the evolution towards a more protein-rich diet, demand that agricultural production continuously rises. Today almost half of the global population is relying on synthetic N and P fertilizers for food production, rendering the supply of these nutrients as a prerequisite for global food security. Moreover, agriculture demands 3% of the world's energy supply. The predominant fraction of this (80%) is needed for the production of mineral fertilizers, mainly N (87%) and P (9%) (Gellings and Parmenter 2004). More efficient resource management is thus key to secure the global food production. Further focus on the nutrient use efficiencies across the different sectors of the economy and the transition from a fossil to a bio-based economy are thereby essential.

The region of Flanders in Belgium has due to its high population density, intensive livestock production and industry a nutrient surplus available in waste streams such as animal manure, organic biological waste and wastewaters. It therefore possesses a large potential towards the recovery and reuse of nitrogen and phosphorus. In this study, a substance flow analysis study for nitrogen and phosphorus is presented, in which the fluxes, stocks and hot spots of both nutrients are quantified throughout the economy in Flanders. The relations between the economic and environmental processes are discussed, with particular focus on manure processing, waste management and the nutrient recovery alternatives for the different waste streams.

Material and Methods

The quantification of the nitrogen and phosphorus flows and stocks was performed for the reference year 2009 and within the spatial system boundaries of the region of Flanders in Belgium. A substance flow analysis (SFA) model was developed using the software tool STAN, which allows balancing of SFA systems through error propagation and data reconciliation (Cencic and Rechberger 2008). The model is defined by 7 main processes: *Air, Water, Soil, Industry, Waste management.* Further focus is placed on the process *Waste management*, which is defined by the sub processes *Composting, Industrial digesters, Incineration, Landfill, Wastewater treatment* and *Manure processing*. For *Manure processing* the distinction is also made between the different manure processing technologies applied in Flanders: *Activated sludge treatment, Agro-digesters, Manure drying* and *Substrate production*. The 21 different processes are interlinked by 160 individual nutrient flows of nitrogen and phosphorus. This results in a mathematical model that comprises 517 equations and 937 variables. Data collection for the different economic and ecological processes was performed with a bottom-up approach through the participation in this study of national and regional sector federations and governmental agencies and through consultation of companies. Nutrient fluxes were obtained by multiplying the mass flow of the individual resources, products and waste streams with their specific nitrogen and phosphorus content. Where possible, multiple data sets were used to cross-check results and obtain reliable fluxes. Uncertainties of the different types of collected data were defined according to the data uncertainty interval method of Cooper and Carliell-Marquet (2013). The nutrient flows are expressed in kg N cap^{-1} yr^{-1} and kg P cap^{-1} yr^{1} to allow comparison with other regions and processes.

Results and Conclusions

In this study the nitrogen and phosphorus balance was quantified for the region of Flanders in Belgium. To our knowledge this study is the first in which both the nitrogen and phosphorus fluxes are quantified on a regional scale level. The presence of strong industrial activity in Flanders is supported by intensive Haber-Bosch N-fixation (90 kg N cap-1 yr-1) and the processing of important amounts of phosphate ore (7.4 kg P cap-1 yr-1). The interaction with the rest of the economy is nevertheless limited and mainly takes place through the use of mineral fertilizers (10 kg N cap-1 yr-1 and 0.22 kg P cap-1 yr-1), food (9.2 kg N cap-1 yr-1 and 0.67 kg P cap-1 yr-1) and non-food products (1.4 kg N cap-1 yr-1 and 0.27 kg P cap-1 yr-1). The predominant nutrient fluxes within the Flemish economy are found within the food supply chain, which connects industry, agriculture and consumption. Here the intensive livestock production in Flanders is notable, as the predominant part of the crops (87% of N and 84% of P) produced are used as fodder and also 21 kg N cap-1 yr-1 and 4.7 kg P cap-1 yr-1 of animal manure is produced. Considering the nutrient balance per sector, the production efficiencies are calculated based on the conversion of input resources to marketable products. The food supply nexus results in an overall fertilizer-to-food efficiency of 19% N and 15% P for animal products and 47% N and 48% P for vegetable products. For the total production in Flanders, including the recycling of manure and fodder byproducts, an overall fertilizer-to-consumer efficiency of 14% N and 14% P is achieved (figure 1).

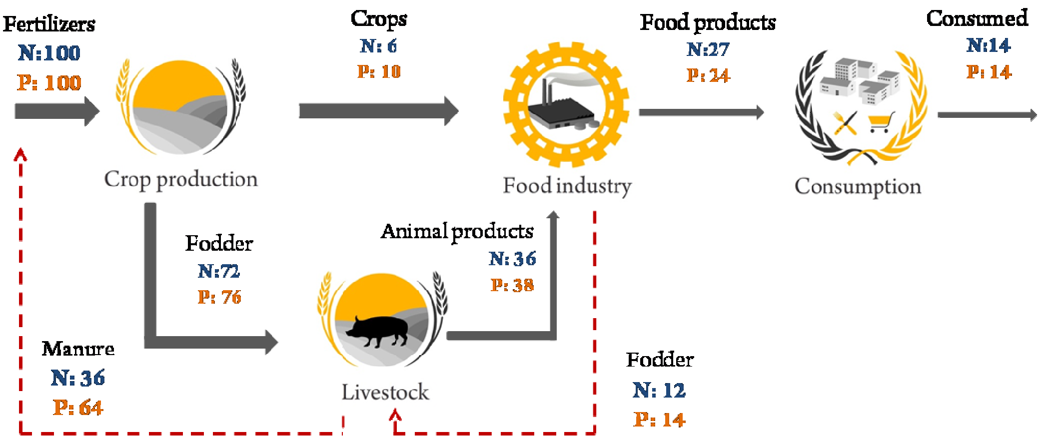

Figure 1. The nitrogen (blue) and phosphorus (orange) conversion efficiency of the food supply chain in Flanders

Similar to the carbon footprint, the N and P footprint are defined as the total amount of anthropogenic emissions of reactive N and P to the environment. Flanders has a N and P footprint of 20 kg N cap^{-1} yr^{-1} and 0.53 kg P cap^{-1} yr^{-1}, respectively, with agriculture contributing strongly to both the N and P footprint (49% of N and 36% of P). The nutrient footprint of Flanders is thereby lower than the EU and US average, which is mainly due to the advanced sewage treatment and manure processing.

At the end of the production and consumption chain a total of 17 kg N cap^{-1} yr^{-1} and 8.3 kg P cap^{-1} yr^{-1} of nutrients culminate in waste streams. Excess manure (20% of N and 11% of P), organic wastes from the food industry (14% of N and 17% of P) and domestic wastewater (19% of N and 6% of P) are the predominant waste streams (Figure 1). Only a fraction of these nutrients (17% of N and 12% of P) is currently recycled, as the technologies applied focus mainly on nutrient removal; thereby missing the opportunity for more sustainable nutrient management. The food supply chain as it stands has an energy demand of 220 MJ kg^{-1}food-N.

Several nutrient recovery strategies were evaluated for their economic feasibility and their impact on the energy demand of the total food supply chain. In particular, the innovative up-cycling of nutrients through the production of microbial single cell protein (SCP) as heterotrophic bacteria, hydrogen-oxidizing bacteria and microalgae for both fodder and food-grade application was assessed. These SCP strategies could increase the nutrient use efficiency by reducing the losses resulting from crop and livestock production, yet would result in an increase of the energy demand by 26% to 276 MJ kg^{-1}food-N. This seems a very affordable cost in view of the leveraging sustainability profits related to high savings in water and land usage.

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